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A THERMOCHEMICAL ANALYSIS OF PROPOSED WORKING FLUIDS FOR ELECTROTHERMAL GUNS

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The thermochemical equilibrium code BLAKE has been used to calculate the thermochemical properties of a variety of mixtures for possible use as working fluids in an electrothermal (ET) gun. The mixtures studied included water, octane/hydrogen peroxide, titanium hydride/aluminum/water, and lithium borohydride/water. The relative merits of each of these mixtures will be discussed as well as possible applications.

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I. INTRODUCTION

The electrothermal accelerator (ET gun) is an advanced hypervelocity propulsion concept currently under study at the US Army Ballistic Research Laboratory. In the ET process, electrical energy is introduced into a plasma-generating capillary through a wire connecting the forward and rear electrodes of the capillary. A high current flows through the wire, causing it to explode, thereby establishing the plasma. The plasma flows rapidly out of the capillary and into the chamber containing the working fluid. Simultaneously, the plasma is replenished by ablation of the polyethylene wall surrounding the discharge. The resulting dissociation of the working fluid through its interaction with the plasma results in a pressure rise and subsequent acceleration of the projectile. The final step of the process occurs after the plasma jet has been extinguished. During this phase, the projectile is acted upon by the expanding gases produced during the dissociation process. The entire ET process can be seen schematically in Figure 1.

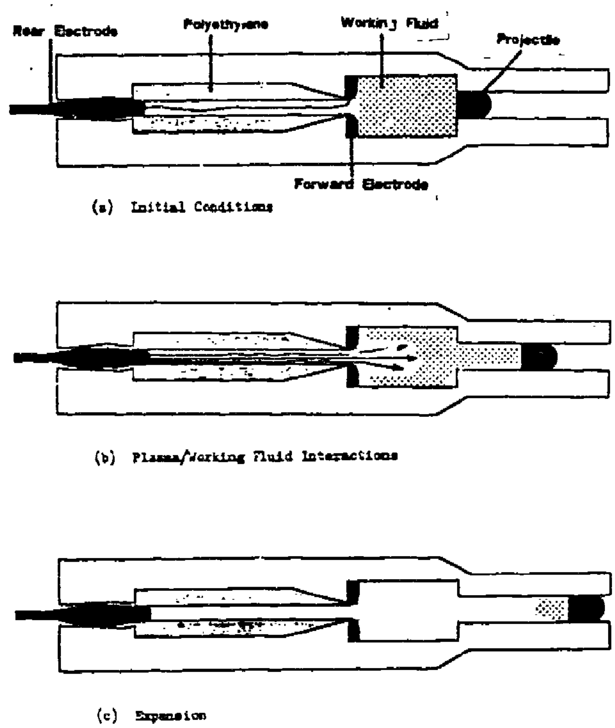

Figure 1. Schematic of the ET Process

This paper reports on a theoretical study that was undertaken to evaluate the relative merits of potential working fluids through an analysis of their thermochemical properties. These properties can then be used in interior ballistic codes to estimate the performance of the fluid as a propellant in an ET weapon system by computing the velocity of the projectile. Table 1 gives a listing of each of the fluids that were studied. The fluids are arranged into three general classes: endothermic mixtures, mildly exothermic mixtures, and highly exothermic mixtures. For the purpose of this paper, endothermic

mixtures are mixtures which have an effective energy density (impetus/(gamma-1)) less than the amount of electrical energy added. Mildly exothermic mixtures have an effective energy density in the range from approximately equal and up to 20% greater than the amount of electrical energy added, and highly exothermic mixtures have an effective energy density that is more than 20% greater than the amount of electrical energy added. These definitions are illustrated graphically in Figure 2.

Table 1. Working Fluids On Which Thermochemical Calculations Have Been Performed (% Mass)*

ENDOTHERMIC MIXTURES

50% Aluminum/50% Water
Water
Lithium Hydride
5% Lithium Hydride/95% Methanol
Hydrogen
50% Titanium Hydride/50% Water

MILDLY EXOTHERMIC MIXTURES

40% Lithium Borohydride/60% Water
Methanol
Octane
45% Lithium Hydride/55% Water
Hydrogen Peroxide
12.5% Titanium Hydride/37.5% Aluminum/50% Water

HIGHLY EXOTHERMIC MIXTURES

Liquid Gun Propellant "1845"
20% Lithium Hydride/80% Hydrogen Peroxide
JA2
25% Octane/75% Hydrogen Peroxide
20% Kerosene/80% Hydrogen Peroxide

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*100% hydrogen peroxide was used in working fluids containing hydrogen peroxide.

In this report, four mixtures are discussed which exhibit general trends seen for the various classes. The working fluids to be reported on in this paper include water (H_2O), a mixture of aluminum (Al), titanium hydride (TiH_2), and water, a mixture of octane (C_8H_{18}) and hydrogen peroxide (H_2O_2), and a mixture of lithium borohydride ($LiBH_4$) and water. Water was chosen as an example of endothermic mixtures which produce moderate molecular weight products. The lithium borohydride/water mixture is a mildly exothermic mixture, which produces predominantly hydrogen gas, a very low molecular weight product. The titanium hydride/aluminum/ water mixture is mildly exothermic and produces low molecular weight products. The addition of titanium hydride serves two purposes: firstly, it serves as a hydrogen gas generator, and secondly, its reaction with water produces titanium oxide which may act as a barrel coating agent thus protecting the gun from erosion.[1] The octane/hydrogen peroxide mixture is highly exothermic which produces moderate molecular weight products. Detailed thermochemical properties for all potential working fluids listed in Table 1 are given in Appendix A. In all mixtures containing hydrogen peroxide, it was decided to use 100% peroxide. While this may not be practical based upon handling concerns, it should, in theory, give the highest impetus possible for mixtures containing hydrogen peroxide.

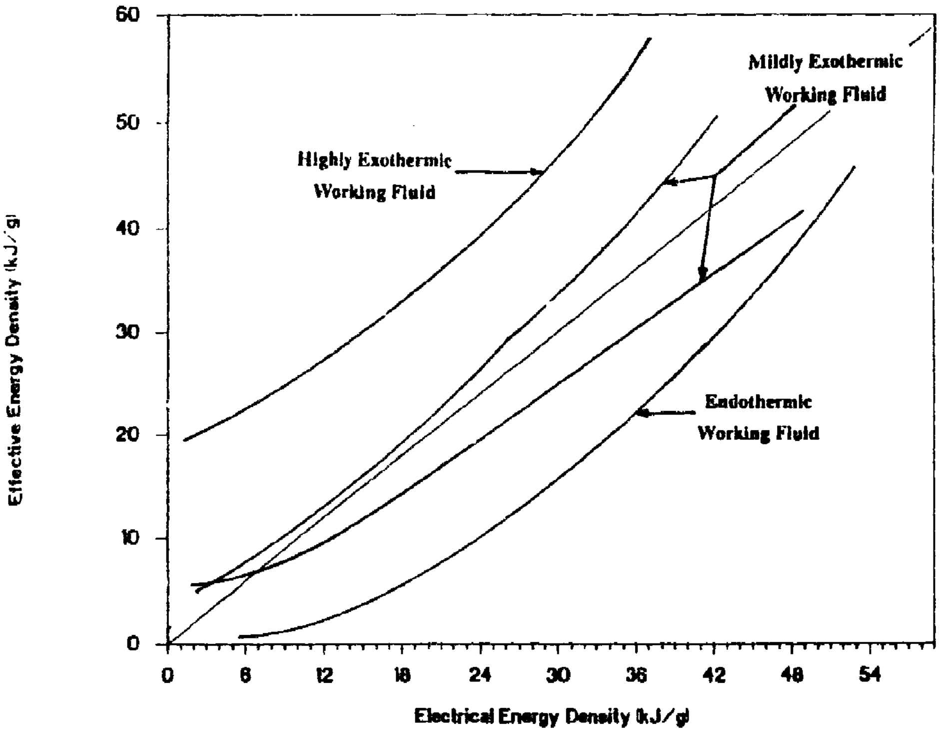

Figure 2. Effective Energy Density vs. Electrical Energy Input Plots for Endothermic, Mildly Exothermic, and Highly Exothermic Mixtures

II. APPROACH

The thermodynamic equilibrium code BLAKE was used to calculate the thermochemical properties of the mixture resulting from the interaction of the working fluid and plasma. BLAKE was specifically written to compute the properties of gun propellants at chamber conditions, namely pressures up to 700 MPa and temperatures between 1500 and 3000 K;[2] however, the results are valid for temperatures up to approximately 6000 K. Under these conditions, the gases are too dense to use the ideal gas equation of state to calculate their thermochemical properties. The truncated virial equation of state is more applicable to gases under these conditions; hence, it has been incorporated into BLAKE as the equation of state.[3] The gases produced in the ET process are created under the same temperature and pressure conditions as the gases resulting from the combustion of conventional gun propellants. Since BLAKE has been successfully used to calculate the thermochemical properties of conventional propellants,[2] it is our belief that BLAKE is the code of choice for calculating the thermochemical properties of ET mixtures.

Equation 1 is the truncated virial equation. In this equation, P is the pressure in atmospheres, V is the volume in liters, n is the number of moles of gas, R is the universal gas constant, and T is the temperature in degrees Kelvin. The constants B (T) and C (T) are the second and third virial coefficients. The virial coefficients are calculated using the Lennard-Jones 6,12 intermolecular potential function. For more details on the truncated equation, the reader is referred to Freedman's report.[2]

$$PV = nRT\,[1 + (n/V)B(T) + (n/V)^2 C(T)] \tag{1}$$

To perform the thermochemical calculations, an initial loading density is considered. The loading density is a ratio of the working fluid mass to the chamber volume. For each mixture, the thermochemical properties were computed at a loading density of 0.2 g/cc. This loading density is typically used in interior ballistic calculations because it takes into account the volume of the chamber and the volume of the barrel. The equilibrium properties computed include the temperature, pressure, impetus, average molecular weight of the gas phase products, co-volume, frozen gamma, and the concentrations of the species generated from the reactions. For the purpose of this study, the properties of most interest are temperature and impetus. Propellant impetus, I, is used by ballisticians to describe the potential of a propellant to do work. It is defined as:

$$I = RT/m \tag{2}$$

where R is the universal gas constant, T is the flame temperature, and m is the average molecular weight of the gaseous combustion products. It can be seen from Eq. (2) that the impetus of a mixture is inversely proportional to the molecular weight of the products at a fixed temperature. In systems where the final products include condensed phase products, Eq. (2) is more appropriately expressed as:

$$I = (M/M_{TOT})\ RT/m \tag{3}$$

where M is the mass of the gas phase products and M_{TOT} is the total mass of the products (gas phase and condensed phase). BLAKE uses Eq. (3) to calculate the impetus of a mixture.

One of the difficulties encountered in calculating the thermochemical properties of the various mixtures was how to handle the interaction of the plasma and the working fluid. The plasma typically consists of dissociated ionized polyethylene with a temperature of several tens of thousands degrees Kelvin. BLAKE is unable to accommodate atoms or ions as input constituents to the code. Thus, it was decided to simulate the plasma as a high energy, low molecular weight constituent.[4] To allow for the direct comparison of the calculated thermochemical properties of each of the mixtures, the amount of electrical energy (plasma) per gram of working fluid (KJ/g) was varied by 1 KJ/g increments. The thermochemical properties of the solid gun propellant JA2 were used as benchmarks to assess the performance potential of the ET working fluid/plasma mixtures. JA2 has excellent propellant properties with an impetus of 1143.9 J/g at a flame temperature of 3424 K.

For each of the ET mixtures studied, it was desired to determine the optimum impetus as a function of the mass ratio of the components. Two approaches were considered for determining the optimum. The first approach was to calculate the thermochemical properties of the stoichiometric mixture without any electrical energy added. The major advantage of this method is that the thermochemical properties of a mixture in which complete combustion of the mix would occur are calculated. The second approach was to use the mixture that provided the highest impetus, again without any electrical energy added to the system. The chief advantage of this approach is that the mixture with the highest impetus will, theoretically, provide the best performance in a gun. For either approach, the temperature of the optimum mixture was constrained to a temperature below 3400 K (for reasons that will be discussed later). Figure 3 shows that a stoichiometric mixture of octane/hydrogen peroxide (approximately 10% octane/90% hydrogen peroxide by weight) has an impetus less than the maximum. The solid vertical line at approximately 77% hydrogen peroxide is the point at which the temperature of the mixture at equilibrium reaches 3400 K. All mixtures to the left of this line have a temperature less than 3400 K; those to the right of this line have a temperature greater than 3400 K. From the figure, it can be seen that the stoichiometric mixture also has a higher than acceptable temperature. To find the optimum mix, a series of BLAKE calculations were performed for each mixture whereby the concentration of each of the components of the mix were varied by 5% by weight. For example, calculations were made for 95% octane/5% hydrogen peroxide down to a 5% octane/95% hydrogen peroxide mix, each time decreasing the octane mix by 5% and increasing the hydrogen peroxide concentration by 5%. The mixture that produced the highest impetus within the temperature constraint was then selected as the optimum mixture and was used for the set of calculations in which electrical energy was added. The optimum mixtures were found to be 25% octane/75% hydrogen peroxide, 40% lithium borohydride/60% water, and a 50%/50% mix of aluminum/water and titanium hydride/water, which is equivalent to 12.5% titanium hydride/37.5% aluminum/50% water. Table 2 lists the thermochemical properties of each of these mixtures to which 5 KJ/g of electrical energy has been added. The thermochemical properties of JA2 (without the addition of electrical energy) are also shown in Table 2.

III. RESULTS AND DISCUSSION

Figure 4 shows a plot of the impetus versus temperature for each of the mixtures studied, the benchmark, JA2, and the conventional solid propellants M30 and M31E1. Each of the data points represent the amount of electrical energy added per mass of compound (KJ/g); for the lithium borohydride/water mix, this ratio varies from 0 to 17, for the octane/peroxide 0 to 5, for water 3 to 10, and 0 to 5 for the titanium hydride/aluminum/water mixture. The solid line through the data points is a linear least squares fit. Figure 4 has been divided into 4 regions, with JA2 serving as the center. Region 1 is the area of high temperature (above 3400 K) and high impetus. If conventional wisdom were to prevail, the maximum desired temperature in a fielded weapon is approximately 3400 K, due to barrel erosion resulting from the high temperature gases. Therefore, all mixtures with data points in region 1 may not be suitable for application in an ET gun. In practice, however, hydrodynamic and nonequilibrium thermodynamic considerations may reduce possible bore erosion in ET guns. Early observations have indicated little or no evidence of barrel erosion in ET gun firings in high temperature situations.[5] It is hypothesized that a thin coating of unvaporized fluid may temporarily protect the inner gun surfaces from the hot gases, possibly extending the temperature range for the working fluids. Experimental efforts to evaluate this effect are planned.[6] Thus, the high impetus of these mixtures may justify their use in an ET weapon despite their high temperature.

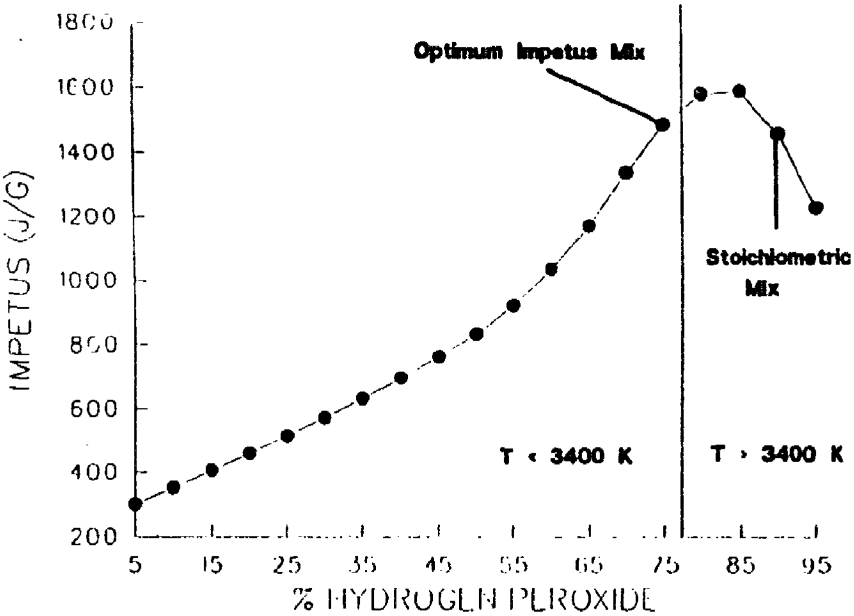

Figure 3. Impetus vs. Concentration Plot for Octane/Hydrogen Peroxide Mixtures

Table 2. Thermochemical Properties of the Mixtures Studied

	$LiBH_4$/Water	$Al/TiH_2/H_2O$	H_2O	C_8H_{18}/H_2O_2	JA2
Electrical Energy Input (KJ/g)	5	5	5	5	0
Temperature (K)	1966	4725	1855	4784	3424
Pressure (MPa)	331.85	294.09	174.11	624.42	285.34
Impetus (J/G)	1235.7	1256.1	856.4	2626.6	1143.9
Mol Wt Gas	9.007	4.54	18.014	16.393	24.836
Co-Volume (cm^3/g)	1.276	0.729	0.082	1.114	0.991
Gamma	1.2296	1.2496	1.2987	1.2113	1.2254
Total Gas Produced (moles/kg of compound)	75.59	31.97	55.51	61.00	40.18
Total Condensed Produced (moles/kg of compound)	7.78	7.42	0	0	0

Region 2 is the ideal regime for a working fluid, because it represents the area of high impetus and low temperature. A working fluid with these characteristics should provide high performance in a gun system with little concern of barrel erosion due to high temperature gases. Working fluids falling within region 3 are low impetus-low temperature propellants. Despite the lower impetus, this region does not represent unacceptable characteristics for gun propellants. As can be seen in the figure, M31E1, a solid propellant currently used in artillery applications, and M30, a propellant used in air defense applications fall within this regime. Working fluids within region 4 exhibit the properties of low impetus and high temperature. These fluids are unacceptable for use in an ET gun system since the impetus calculated for these mixtures is too low to justify the use of such a high temperature mixture.

There are two qualitative trends that can be observed from the data plots in Figure 4. Firstly, the addition of electrical energy serves to increase the impetus as well as the temperature of all the mixtures. Secondly, the additon of electrical energy does not result in an equal increase in impetus and temperature from mixture to mixture. This can be seen in the differences in the slope of the least squares fit to the data. The reasons for the differences in these slopes will be discussed below.

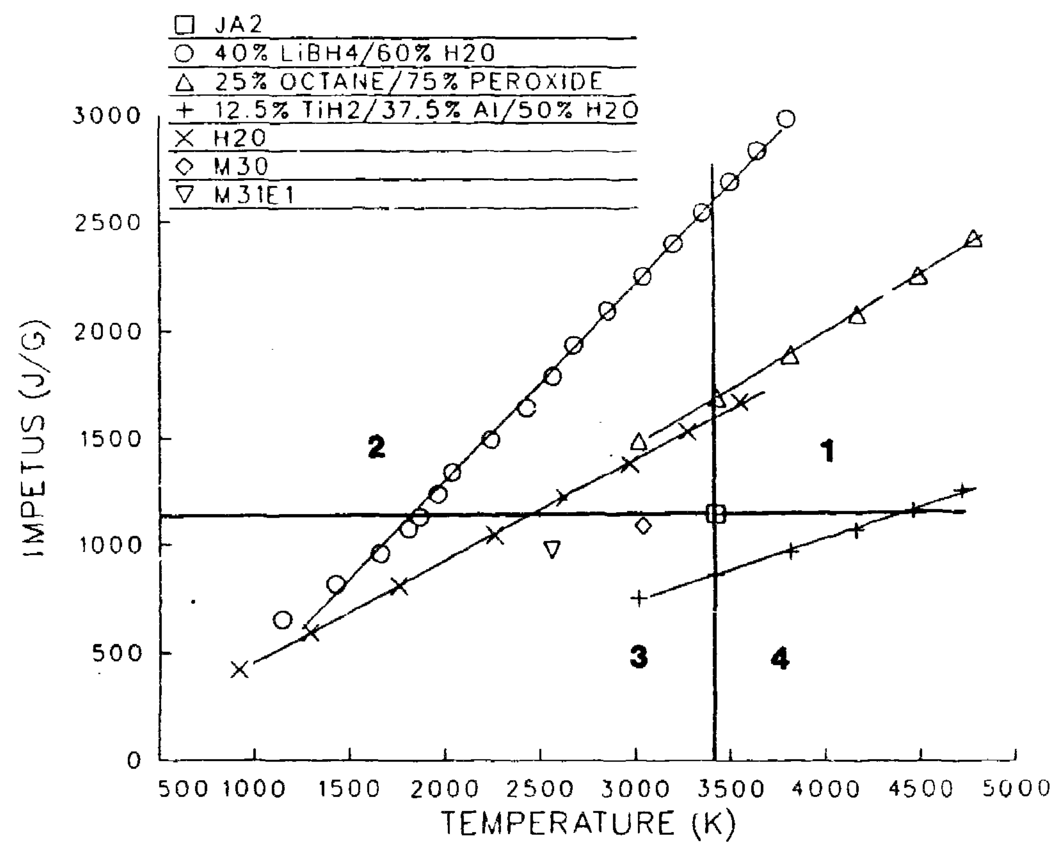

Figure 4. Impetus vs. Temperature Plots for 25% Octane/75% Hydrogen Peroxide, 12.5% Titanium Hydride/37.5% Aluminum/50% Water, 40% Lithium Borohydride/60% Water, Water, JA2, M30, and M31E1

As stated earlier, water represents the class of endothermic systems that produce moderate molecular weight products and is used as a baseline comparison in this study. As electrical energy is added, complete vaporization of the water occurs, resulting in water vapor being the predominate final product. The slope of the data points in this system is indicative of the slope seen for mixtures that produce moderate molecular weight gas phase products. Water is essentially a region 3-region 2 propellant. As can be seen in Figure 4, the borohydride/water mixture has a higher impetus over the same temperature range, hence, it is unlikely that water would be used in a fielded weapon.

The titanium hydride/aluminum/water system is substantially hotter than the water system. It is also important to notice the decrease in the slope of the fit to the data points in the titanium hydride/aluminum/water mixture in comparison to the water system. This is due to the fact that this reaction produces approximately 8 moles of condensed phase species, namely liquid Al_2O_3 and liquid Ti_3O_5, per kilogram of working fluid while producing only 32 moles of gas. These condensed phases serve to deplete the availability of propulsion gases, thereby decreasing the impetus. From the data presented in Figure 4, this mixture is a region 4 propellant, and for reasons presented earlier, is not a likely candidate for use as a propellant in an ET gun.

The two most promising mixtures studied, in terms of impetus and temperature, are the octane/peroxide and lithium borohydride/water mixtures. One of the attractive features of the octane/peroxide mixture is the increase in impetus at approximately the same flame temperature as JA2. When 1 KJ of electrical energy is added to 1 gram of the octane/peroxide mixture, the calculated impetus is 1694.6 J/G. This is a 48% increase over JA2, a high impetus propellant. The increase in impetus of the octane/peroxide mixture (compared to the titanium/hydride/aluminum/water mixture) is due to the fact that no condensed phase products are formed; the major products are gaseous H_2O, H_2, CO, and CO_2. The slope of the least squares fit is very similar to that of water indicating the formation of these average molecular weight gas products. The other attractive feature is the relatively low power requirements necessary to achieve this high impetus compared to the other mixtures. This working fluid may be useful in an application which requires a high impetus propellant with low power requirements and which can tolerate a higher temperature.

The lithium borohydride/water mixture is a Region 2 propellant which offers a reasonably high impetus propellant system with a very low flame temperature. However, there are several concerns with this working fluid. First, metal hydrides, such as lithium borohydride, react vigorously with water liberating hydrogen gas, both an advantage and a disadvantage. On the positive side, 62-64 moles of hydrogen gas are liberated per kilogram of mix. It is the presence of this low molecular weight gas that provides the propulsive force necessary to drive the projectile. There are about 8 moles of condensed phase products per kilogram of working fluid produced in the reaction, however, their concentration is negligible in comparison to the hydrogen gas. It is also the presence of hydrogen in such high quantities that serves to increase the calculated impetus. This is also the reason for the large slope in the fit of the data points shown in Figure 4. On the negative side, the generation of such large quantities of hydrogen may cause difficulties. As the "hot" hydrogen gas exits the muzzle of the gun, its reaction with "cool" atmospheric oxygen may create a large muzzle flash. It is hypothesized that the presence of lithium metal ions in the muzzle effluent may help to interrupt the reaction network, thus preventing muzzle flash. Programs for evaluating the potential occurrence of muzzle flash in gas mixtures are currently available.[7] Such computations would seem to be an important first step in examining candidate working fluid systems in general.

A second concern is that the reactivity of the lithium borohydride and water may necessitate their physical separation until the plasma jet enters the chamber. The lithium borohydride may be able to be encapsulated in a material that does not react with water. As the plasma jet enters the chamber, the jet will dissociate and ionize the encapsulation material, thus allowing the borohydride-water reaction to proceed. A third concern is the high power requirements necessary to raise the impetus to levels comparable with the octane/peroxide system. However, the lithium borohydride/water system would be very attractive for applications in which low flame temperature is required.

IV. CONCLUSIONS

A thermochemical study has been completed to evaluate the relative merits of several candidate working fluids in an ET gun. The flame temperatures of the 25% octane/75% hydrogen peroxide system and the 12.5% titanium hydride/37.5% aluminum/50% water system are roughly comparable for equivalent electrical energy input, however the octane/peroxide mix yields a higher impetus. In fact, the octane/peroxide mixture is calculated to have a higher impetus than JA2, a commonly used solid gun propellant. The 40% lithium borohydride/60% water system is an attractive candidate working fluid in systems which require a low flame temperature. For all of the mixtures studied, the impetus and temperature of the mixture are shown to increase as the amount of electrical energy added to the system increases. However, the magnitude of the increase in impetus and temperature varies from mixture to mixture despite the addition of equivalent amounts of electrical energy. The differences in the magnitude of the increase is due to the formation of different amounts of low molecular weight final products.

Future studies will include interior ballistic computations for representative ET gun systems based upon these thermochemical calculations. Gas temperature and heat transfer measurements will also be considered since barrel erosion is a major concern at high temperatures. The application of encapsulation techniques to the lithium borohydride/water system will also be investigated.

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APPENDIX A

Thermochemical Values for Various Working Fluids in Combination with Electrical Energy Input

TABLE A-1. Aluminum & Water

Working Fluid: Aluminum (Al) - 50% / Water (H_2O) - 50%

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
0	3485	189.32	813.2	2.359	0.705	1.2734	2.97
1	3837	210.82	905.1	2.741	0.707	1.2671	3.39
2	4145	231.92	994.6	3.269	0.712	1.2623	3.79
3	4435	252.58	1081.4	3.894	0.719	1.2587	4.18
4	4686	272.81	1165.7	4.565	0.727	1.2561	4.55

TABLE A-2. Water

Working Fluid: Water (H_2O)

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
3	917	61.92	423.1	18.015	-1.834	1.9414	0.44
4	1413	122.13	652.3	18.014	-0.342	1.4	1.63
5	1855	174.11	856.4	18.014	0.082	1.2987	2.86
6	2261	221.38	1044.2	18.001	0.283	1.2557	4.08
7	2633	265.08	1218.3	17.967	0.404	1.2323	5.24
8	2971	305.89	1380.1	17.896	0.488	1.2182	6.32
9	3276	344.47	1531.6	17.783	0.554	1.2093	7.31
10	3552	381.53	1675.1	17.633	0.609	1.2035	8.23
11	3805	417.67	1813.1	17.45	0.659	1.1998	9.07
12	4038	453.37	1947.3	17.242	0.705	1.1975	9.85
13	4256	489.03	2079.6	17.015	0.748	1.1962	10.59
14	4461	524.88	2210.9	16.775	0.788	1.1958	11.29
15	4655	561.15	2342.2	16.526	0.826	1.1959	11.95
16	4842	597.99	2474	16.272	0.863	1.1964	12.59
17	5022	635.56	2607.2	16.015	0.898	1.1973	13.21
18	5196	673.92	2741.9	15.757	0.931	1.1985	13.81
19	5366	713.12	2878.3	15.501	0.964	1.1998	14.40
20	5533	753.27	3016.9	15.248	0.995	1.2014	14.97
21	5696	794.4	3157.8	14.998	1.025	1.203	15.55
22	5857	836.56	3301.1	14.753	1.054	1.2048	16.11
23	6017	879.77	3447.1	14.512	1.082	1.2066	16.68

Working Fluid: Lithium Hydride (LiH)

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
25	569	189.27	594.7	7.949	1.858	1.4791	1.24
26	858	303.46	897.5	7.947	2.042	1.4117	2.17
27	1125	408.29	1178.8	7.936	2.113	1.3771	3.12
28	1374	506.61	1443.8	7.914	2.15	1.356	4.05
29	1611	601.55	1699.3	7.883	2.175	1.3419	4.97
30	1840	695.02	1949.5	7.848	2.195	1.3316	5.87
31	2065	788.33	2197.9	7.81	2.212	1.3237	6.78
32	2286	881.88	2445.6	7.772	2.227	1.3173	7.70
33	2506	976.01	2693.9	7.735	2.24	1.3119	8.63
34	2725	1070.7	2943.3	7.698	2.251	1.3072	9.58
35	2943	1165.54	3192.9	7.664	2.261	1.3031	10.53
36	3160	1260.69	3443.3	7.631	2.269	1.2994	11.50
37	3376	1355.69	3693.4	7.6	2.276	1.296	12.47
38	3590	1450.35	3942.7	7.572	2.282	1.2928	13.46
39	3803	1545	4191.9	7.543	2.287	1.2898	14.46
40	4013	1639.02	4439.4	7.516	2.291	1.2869	15.47
41	4220	1732.61	4685.4	7.489	2.296	1.2842	16.48
42	4425	1825.65	4929.7	7.463	2.3	1.2815	17.51
43	4627	1918.23	5172.3	7.437	2.304	1.2788	18.55
44	4826	2010.31	5413	7.412	2.307	1.2762	19.59
45	5021	2101.91	5652	7.387	2.311	1.2737	20.65
46	5214	2193.06	5889.2	7.361	2.315	1.2711	21.72
47	5404	2283.75	6124.6	7.336	2.318	1.2686	22.80
48	5591	2374.08	6358.4	7.31	2.322	1.2661	23.89
49	5775	2464.07	6590.7	7.285	2.325	1.2637	24.99
50	5956	2553.74	6821.4	7.259	2.329	1.2612	26.11

TABLE A-4. Lithium Hydride & Methanol

Working Fluid: Lithium Hydride (LiH) - 5% / Methanol (CH_3OH) - 95%

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
1	1356	148.21	553.7	16.424	1.264	1.2115	2.61
2	1507	184.81	670.3	15.781	1.373	1.2075	3.23
3	1643	220.69	796.1	15.195	1.392	1.2084	3.82
4	1763	261.68	932.8	14.634	1.436	1.2117	4.40
5	1864	305.09	1075.6	14.350	1.475	1.2140	5.02
6	2052	372.83	1254.7	13.599	1.635	1.2193	5.72
7	2262	432.37	1448.4	12.987	1.650	1.2241	6.46
8	2378	437.26	1515.2	12.606	1.535	1.2272	6.66
9	2432	438.16	1517.9	12.350	1.536	1.2294	6.61
10	2483	441.26	1528.4	12.146	1.536	1.2313	6.60
11	2533	446.54	1546.5	11.980	1.537	1.2328	6.64
12	2584	453.85	1571.8	11.844	1.537	1.2340	6.71
13	2636	462.89	1603.2	11.733	1.537	1.2350	6.82
14	2689	473.19	1638.9	11.641	1.536	1.2357	6.95
15	2741	484.15	1677.1	11.564	1.536	1.2363	7.09
16	2793	495.23	1715.8	11.498	1.535	1.2368	7.24
17	2842	506.17	1754.0	11.440	1.535	1.2372	7.39
18	2890	516.75	1791.1	11.387	1.534	1.2376	7.53
19	2936	526.86	1826.6	11.341	1.533	1.2378	7.68
20	2979	536.52	1860.6	11.298	1.532	1.2381	7.81
21	3022	546.09	1894.3	11.258	1.531	1.2383	7.94
22	3062	554.85	1925.3	11.222	1.530	1.2385	8.07

Working Fluid: Lithium Hydride (LiH) - 5% / Methanol (CH_3OH) - 95%

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
23	3101	563.30	1955.2	11.190	1.529	1.2386	8.19
24	3138	571.39	1983.9	11.160	1.528	1.2387	8.31
25	3173	579.17	2011.4	11.132	1.527	1.2388	8.42
26	3208	586.67	2038.0	11.105	1.526	1.2389	8.53
27	3241	593.85	2063.5	11.082	1.525	1.2389	8.63
28	3273	600.80	2088.2	11.059	1.524	1.2390	8.73
29	3304	607.53	2112.1	11.038	1.523	1.2390	8.83
30	3334	614.03	2135.3	11.018	1.523	1.2390	8.93
31	3364	620.33	2157.7	11.000	1.522	1.2390	9.02
32	3392	626.43	2179.3	10.983	1.521	1.2390	9.11
33	3420	632.36	2200.4	10.967	1.520	1.2390	9.20
34	3447	638.11	2220.9	10.951	1.520	1.2390	9.29
35	3473	643.71	2240.9	10.937	1.519	1.2390	9.37
36	3499	649.17	2260.3	10.923	1.518	1.23890	9.4
37	3524	654.48	2279.2	10.910	1.518	1.23890	9.5
38	3549	659.68	2297.7	10.897	1.517	1.23890	9.6
39	3573	664.74	2315.7	10.886	1.516	1.23880	9.6
40	3596	669.68	2333.3	10.875	1.516	1.23880	9.7
41	3619	674.50	2350.5	10.864	1.515	1.23870	9.8
42	3641	679.22	2367.2	10.854	1.515	1.23860	9.9
43	3663	683.84	2383.7	10.844	1.514	1.23860	9.9
44	3685	688.36	2399.8	10.835	1.514	1.2385	10.0

TABLE A-4 Cont. Lithium Hydride & Methanol

Working Fluid: Lithium Hydride (LiH) - 5% / Methanol (CH_3OH) - 95%

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
45	3706	692.79	2415.5	10.826	1.513	1.2385	10.1
46	3727	697.10	2430.9	10.818	1.513	1.2384	10.1
47	3747	701.36	2446.0	10.809	1.512	1.2383	10.2
48	3767	705.54	2460.8	10.801	1.512	1.2382	10.3
49	3787	709.64	2475.4	10.794	1.512	1.2382	10.3
50	3806	713.66	2489.7	10.786	1.511	1.2381	10.4
51	3825	717.62	2503.8	10.779	1.511	1.2380	10.5
52	3844	721.51	2517.6	10.773	1.511	1.2380	10.5
53	3862	725.32	2531.1	10.766	1.510	1.2379	10.6
54	3880	729.08	2544.5	10.760	1.510	1.2378	10.7
55	3898	732.78	2557.6	10.753	1.510	1.2377	10.7
56	3915	736.42	2570.5	10.747	1.509	1.2377	10.8
57	3933	740.01	2583.2	10.742	1.509	1.2376	10.8
58	3950	743.54	2595.7	10.736	1.509	1.2375	10.9
59	3966	747.05	2608.1	10.730	1.509	1.2375	10.9
60	3983	750.47	2620.2	10.725	1.509	1.2374	11.0
61	3999	753.84	2632.2	10.720	1.508	1.2373	11.0
62	4015	757.17	2644.0	10.715	1.508	1.2372	11.1
63	4031	760.46	2655.6	10.710	1.508	1.2372	11.1
64	4047	763.70	2667.1	10.705	1.508	1.2371	11.2
65	4062	766.91	2678.4	10.701	1.508	1.2370	11.3

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TABLE A-5. Hydrogen

Working Fluid: Hydrogen (H_2)

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
1	632	1951	2607.6	2.016	3.664	1.3965	6.574
2	715	2237	2947.2	2.016	3.683	1.3955	7.453
3	796	2518	3283.9	2.016	3.696	1.3937	8.342
4	878	2797	3621.8	2.016	3.705	1.3904	9.271
5	960	3072	3960.8	2.016	3.711	1.3858	10.26
6	1043	3344	4299.7	2.016	3.714	1.3807	11.29
7	1124	3611	4637.5	2.016	3.716	1.3742	12.39
8	1205	3873	4971.2	2.016	3.717	1.3677	13.51
9	1285	4130	5298.1	2.016	3.717	1.3617	14.64
10	1362	4382	5618.5	2.016	3.718	1.356	15.78
11	1439	4629	5933.6	2.016	3.718	1.3507	16.91
12	1514	4872	6243.8	2.016	3.719	1.3458	18.05
13	1588	5111	6549.9	2.016	3.719	1.3411	19.20
14	1662	5347	6852.3	2.016	3.719	1.3367	20.35
15	1734	5580	7151.7	2.016	3.718	1.3326	21.50
16	1806	5809	7448.4	2.016	3.718	1.3287	22.66
17	1877	6037	7743	2.016	3.717	1.325	23.82
18	1948	6261	8035.6	2.016	3.717	1.3215	24.99
19	2019	6484	8326.2	2.016	3.716	1.3182	26.16
20	2089	6704	8615	2.016	3.715	1.315	27.34
21	2158	6922	8901.9	2.016	3.714	1.312	28.53
22	2228	7137	9187	2.016	3.713	1.3091	29.72
23	2296	7351	9470.2	2.016	3.712	1.3062	30.92

Working Fluid: Hydrogen (H_2)

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
24	2364	7563	9751.5	2.016	3.711	1.3036	32.11
25	2432	7773	10030.7	2.016	3.71	1.301	33.32
26	2499	7981	10307.9	2.016	3.709	1.2985	34.53
27	2566	8187	10583.2	2.016	3.707	1.2961	35.74
28	2632	8392	10856.6	2.016	3.706	1.2936	36.97
29	2698	8596	11126.4	2.016	3.705	1.2914	38.18
30	2764	8797	11398.6	2.016	3.704	1.2892	39.41
31	2829	8998	11667.2	2.016	3.703	1.287	40.65
32	2894	9197	11934.3	2.016	3.702	1.285	41.87
33	2958	9394	12200	2.016	3.701	1.2829	43.12
34	3022	9590	12464.1	2.016	3.7	1.2809	44.37
35	3086	9786	12727.5	2.016	3.699	1.2789	45.63
36	3149	9980	12989.3	2.016	3.699	1.277	46.89
37	3212	10173	13249.9	2.016	3.698	1.2753	48.12
38	3275	10365	13509.3	2.016	3.697	1.2735	49.39
39	3337	10556	13767.5	2.015	3.696	1.2718	50.65
40	3400	10746	14024.5	2.015	3.695	1.27	51.94
41	3461	10935	14280.3	2.015	3.694	1.2685	53.18
42	3523	11123	14535	2.015	3.693	1.267	54.43
43	3584	11310	14788.6	2.015	3.692	1.2655	55.70
44	3645	11496	15041.1	2.015	3.692	1.2639	56.99
45	3706	11682	15292.4	2.015	3.691	1.2626	58.23
46	3766	11867	15542.7	2.015	3.69	1.2613	59.48

Working Fluid: Hydrogen (H_2)

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
47	3826	12051	15792	2.015	3.69	1.2599	60.76
48	3886	12235	16040.2	2.014	3.689	1.2586	62.02
49	3946	12418	16287.4	2.014	3.688	1.2574	63.27
50	4005	12600	16533.7	2.014	3.688	1.2563	64.50
51	4064	12782	16779.2	2.014	3.687	1.2552	65.74
52	4123	12963	17023.6	2.014	3.687	1.254	67.02
53	4182	13144	17267.1	2.013	3.686	1.2531	68.22
54	4240	13324	17509.7	2.013	3.686	1.252	69.48
55	4298	13504	17751.5	2.013	3.686	1.2511	70.69
56	4356	13684	17992.4	2.013	3.685	1.2502	71.91
57	4413	13863	18232.5	2.012	3.685	1.2493	73.13
58	4470	14042	18471.8	2.012	3.685	1.2486	74.30
59	4527	14220	18710.4	2.012	3.684	1.2478	75.50
60	4584	14398	18948.1	2.012	3.684	1.2469	76.74

TABLE A-6. Titanium Hydride & Water

Working Fluid: Titanium Hydride (TiH_2) - 50% / Water (H_2O) - 50%

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
2	2162	156.35	679.3	6.716	0.655	1.2722	2.50
3	2630	190.84	826.7	6.714	0.668	1.2553	3.24
4	3078	224.06	969.0	6.704	0.675	1.2443	3.97
5	3502	256.18	1106.3	6.682	0.681	1.2370	4.67
6	3899	287.51	1239.2	6.645	0.690	1.2325	5.33
7	4265	318.41	1368.6	6.596	0.702	1.2302	5.95
8	4604	349.27	1495.8	6.546	0.717	1.2294	6.52
9	4917	380.43	1622.4	6.506	0.735	1.2299	7.06
10	5210	412.18	1749.4	6.487	0.756	1.2313	7.56

TABLE A-7. Lithium Borohydride & Water

Working Fluid: Lithium Borohydride ($LiBH_4$) - 40% / Water (H_2O) - 60%

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
0	1147	190.2	657	4.695	1.279	1.3138	2.09
1	1427.	220.06	818.0	4.719	1.283	1.2926	2.8
2	1661.	258.13	959.6	5.098	1.283	1.2752	3.49
3	1811.	288.20	1072.3	6.273	1.279	1.2571	4.17
4	1872.	304.25	1129.7	7.169	1.287	1.2470	4.57
5	1966.	331.85	1235.7	9.007	1.276	1.2296	5.38
6	2039.	358.48	1339.5	10.915	1.263	1.2148	6.24
7	2244.	404.52	1493.7	11.280	1.307	1.2072	7.22
8	2433.	447.61	1646.6	11.304	1.321	1.2044	8.06
9	2572.	490.11	1791.7	11.355	1.344	1.2043	8.77
10	2682.	533.35	1935.1	11.425	1.372	1.2056	9.41
11	2863.	584.58	2094.2	11.367	1.418	1.2044	10.25
12	3045.	630.36	2249.7	11.255	1.431	1.2039	11.03
13	3210.	675.12	2398.9	11.127	1.447	1.2043	11.74
14	3363.	719.25	2543.9	10.992	1.463	1.2052	12.4
15	3510.	763.29	2687.4	10.858	1.479	1.2064	13.02
16	3656.	808.08	2832.7	10.731	1.494	1.2075	13.65
17	3808.	854.13	2982.4	10.615	1.508	1.2084	14.31

Working Fluid: Lithium Borohydride ($LiBH_4$) - 40% / Water (H_2O) - 60%

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
18	3968	901.97	3138.9	10.512	1.520	1.2090	15.02
19	4142	951.69	3303.3	10.426	1.529	1.2091	15.94
20	4331	1003.32	3476.4	10.358	1.535	1.2087	16.66
21	4534	1056.50	3657.3	10.308	1.538	1.2079	17.59
22	4797	1110.67	3843.8	10.272	1.539	1.2067	18.60
23	4971	1165.36	4034.0	10.245	1.538	1.2053	19.65
24	5197	1220.02	4225.7	10.226	1.536	1.2038	20.73
25	5424	1274.36	4417.3	10.210	1.534	1.2023	21.84

TABLE A-8. Methanol

Working Fluid: Methanol (CH_3OH)

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
0	989.	96.72	398.3	18.844	0.882	1.2931	1.36
1	1224	138.8	527.9	18.135	1.197	1.2373	2.22
2	1399	179.8	653.1	17.402	1.368	1.2215	2.94
3	1562	223.3	789.9	16.438	1.464	1.2194	3.60
4	1735	271.5	947.5	15.225	1.511	1.225	4.21
5	1918	325.0	1122.2	14.212	1.547	1.2322	4.83
6	2117	383.9	1314.9	13.387	1.575	1.2396	5.48
7	2336	447.8	1524.6	12.739	1.595	1.246	6.19
8	2576	515.3	1748.3	12.252	1.607	1.2507	6.97
9	2835	584.9	1981.4	11.897	1.613	1.2534	7.81
10	3108	654.9	2218.4	11.65	1.613	1.2542	8.72
11	3391	724.3	2455.5	11.481	1.61	1.2535	9.68
12	3677	792.5	2690.1	11.365	1.606	1.252	10.68
13	3962	859.4	2919.7	11.283	1.603	1.25	11.67
14	4242	924.9	3143.9	11.219	1.601	1.248	12.67
15	4515	988.9	3361.6	11.167	1.601	1.2462	13.65
16	4779	1051.8	3573.9	11.118	1.602	1.2447	14.60
17	5034	1113.8	3781.3	11.07	1.605	1.2434	15.53
18	5282	1175.1	3984.6	11.021	1.609	1.2425	16.43
19	5522	1236.0	4184.5	10.971	1.615	1.2419	17.29
20	5755	1296.8	4382	10.919	1.621	1.2416	18.13
21	5982	1357.4	4577.2	10.866	1.628	1.2414	18.96

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TABLE A-9. Octane

Working Fluid: Octane (C_8H_{18})

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
0	747.	68.46	247.2	15.763	1.39	1.2351	1.05
1	1029	103.42	357.3	14.466	1.546	1.1745	2.04
2	1252	135.89	464.8	12.74	1.579	1.1605	2.89
3	1452	169.02	578.4	11.059	1.578	1.1592	3.63
4	1644	203.56	699.5	9.597	1.564	1.163	4.29
5	1833	239.46	827.1	8.399	1.546	1.1687	4.90
6	2024	276.33	959.1	7.466	1.529	1.1748	5.48
7	2214	313.38	1092.3	6.785	1.515	1.1801	6.06
8	2400	349.63	1222.6	6.343	1.503	1.1839	6.64
9	2577	364.96	1346.3	6.13	1.494	1.186	7.23
10	2741	416.03	1461	6.123	1.488	1.1864	7.83
11	2891	445.48	1566.5	6.289	1.484	1.1853	8.45
12	3027	472.64	1663.6	6.593	1.48	1.1831	9.08
13	3151	497.88	1753.9	7.002	1.477	1.1801	9.73
14	3266	521.64	1838.9	7.489	1.475	1.1767	10.40
15	3373	544.26	1919.8	8.034	1.473	1.1729	11.10
16	3474	565.99	1997.6	8.621	1.471	1.1691	11.81
17	3571	587.05	2073.3	9.237	1.468	1.1651	12.55
18	3665	607.64	2147.3	9.875	1.466	1.1613	13.31
19	3756	627.97	2220.5	10.525	1.464	1.1574	14.10
20	3846	647.98	2292.8	11.183	1.462	1.1537	14.91

TABLE A-9 Cont. Octane

Working Fluid: Octane (C_8H_{18})

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
21	3936	667.96	2365.1	11.845	1.459	1.1502	15.74
22	4025	687.89	2437.5	12.505	1.457	1.1467	16.61
23	4114	707.92	2510.3	13.162	1.454	1.1434	17.50
24	4241	735.23	2609.8	13.51	1.45	1.1417	18.41
25	4427	774.34	2751.7	13.375	1.446	1.1421	19.36
26	4613	813.53	2892.9	13.258	1.444	1.1423	20.32
27	4799	852.78	3033.2	13.154	1.443	1.1426	21.27
28	4983	892.16	3172.7	13.059	1.444	1.1428	22.21
29	5166	931.7	3311.7	12.969	1.446	1.143	23.15
30	5346	971.32	3449.9	12.885	1.448	1.1432	24.09
31	5525	1011.19	3587.8	12.803	1.452	1.1435	25.00
32	5700	1051.3	3725.4	12.722	1.456	1.1438	25.90

TABLE A-10. Lithium Hydride & Water

Working Fluid: Lithium Hydride (LiH) - 45% / Water (H_2O) - 55%

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
0	1388	172.71	653.6	2.026	1.216	1.3552	1.84
1	1621	201.83	763.6	2.032	1.217	1.3380	2.26
2	1845	229.75	869.4	2.040	1.216	1.3244	2.68
3	1852	232.00	872.4	2.040	1.240	1.3240	2.69
4	1945	244.73	917.0	2.050	1.253	1.3190	2.87
5	2162	272.38	1021.2	2.086	1.251	1.3085	3.31
6	2373	299.56	1123.5	2.145	1.249	1.2997	3.75
7	2573	326.19	1223.3	2.235	1.250	1.2921	4.19
8	2762	352.19	1320.1	2.359	1.252	1.2858	4.62
9	2939	377.52	1413.5	2.517	1.256	1.2804	5.04
10	3103	402.19	1503.5	2.705	1.262	1.2760	5.45
11	3255	426.28	1590.4	2.918	1.269	1.2723	5.84
12	3398	449.89	1674.8	3.152	1.277	1.2693	6.22
13	3532	473.14	1757.0	3.403	1.286	1.2667	6.59
14	3659	496.15	1837.7	3.666	1.296	1.2646	6.95
15	3780	518.99	1917.4	3.938	1.306	1.2628	7.30
16	3897	541.78	1996.4	4.217	1.315	1.2613	7.64
17	4025	360.94	1398.7	4.668	1.125	1.2550	5.49
18	4131	379.03	1464.7	4.806	1.136	1.2533	5.78
19	4301	408.09	1572.8	5.010	1.149	1.2509	6.27
20	4471	438.58	1683.4	5.192	1.162	1.2487	6.77

TABLE A-11. Hydrogen Peroxide

Working Fluid: Hydrogen Peroxide (H_2O_2)

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
0	2503	209.68	919.1	22.642	0.617	1.2345	3.92
1	2989	254.91	1102	22.552	0.677	1.2195	5.02
2	3415	296.47	1268.5	22.384	0.721	1.2116	5.99
3	3790	335.59	1423.3	22.137	0.759	1.2078	6.84
4	4124	373.38	1570.7	21.827	0.793	1.2063	7.61
5	4427	410.68	1714.2	21.47	0.826	1.2065	8.30
6	4706	448.08	1856.1	21.082	0.858	1.2076	8.94
7	4968	486.01	1998.3	20.672	0.888	1.2094	9.54
8	5217	524.71	2141.6	20.252	0.918	1.2117	10.11
9	5454	564.34	2287	19.829	0.948	1.2144	10.66
10	5684	605.1	2435.1	19.407	0.976	1.2172	11.21
11	5907	647.07	2586.3	18.99	1.003	1.2201	11.75

TABLE A-12. Titanium Hydride & Aluminum & Water

Working Fluid: Titanium Hydride (TiH_2) - 12.5% / Aluminum (Al) - 37.5% / Water (H_2O) - 50%

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
0	3011.	176.17	757.3	3.383	0.701	1.2707	2.8
1	3423.	200.96	863.9	3.386	0.701	1.2628	3.29
2	3812.	225.44	968.5	3.430	0.704	1.2574	3.76
3	4162.	249.22	1069.0	3.599	0.710	1.2539	4.21
4	4465.	272.03	1164.6	3.966	0.719	1.2514	4.63
5	4725.	294.09	1256.1	4.504	0.729	1.2496	5.03

TABLE A-13. Liquid Propellant LP1845

Working Fluid: Liquid Propellant LP1845

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
0	2694	227.11	971.9	23.042	0.72	1.2149	4.52
1	3102	266.71	1128.8	22.849	0.768	1.2062	5.47
2	3453	303.24	1272.4	22.563	0.804	1.2023	6.28
3	3763	338.22	1408.6	22.214	0.835	1.2009	7.01
4	4046	372.63	1541.3	21.827	0.864	1.201	7.66
5	4309	407.17	1673	21.416	0.891	1.2022	8.27
6	4558	442.16	1805.3	20.994	0.917	1.204	8.84
7	4797	477.89	1939	20.568	0.943	1.2064	9.39
8	5027	514.54	2075	20.143	0.967	1.209	9.92
9	5251	552.27	2213.7	19.721	0.992	1.212	10.44
10	5469	591.08	2355.3	19.307	1.015	1.2151	10.94
11	5684	631.03	2499.9	18.904	1.038	1.2182	11.45
12	5896	672.2	2648	18.512	1.061	1.2215	11.95

TABLE A-14. Lithium Hydride & Hydrogen Peroxide

Working Fluid: Lithium Hydride (LiH) - 20% / Hydrogen Peroxide (H_2O_2) - 80%

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
0	3857	196.84	869.6	17.117	0.582	1.1864	4.67
1	4085	217.13	953.2	16.985	0.614	1.1862	5.12
2	4304	238.74	1039.9	16.810	0.644	1.1869	5.56
3	4515	261.14	1129.8	16.599	0.674	1.1882	6.00
4	4720	284.52	1222.8	16.362	0.702	1.1901	6.43
5	4919	308.86	1318.8	16.106	0.730	1.1923	6.86

TABLE A-15. JA2

Working Fluid: JA2

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
0	3424	285.34	1143.9	24.886	0.991	1.2254	5.07
1	3959	333.38	1333.5	24.686	1.000	1.2219	6.00
2	4401	376.93	1503.5	24.337	1.011	1.2219	6.77
3	4776	418.26	1662.8	23.882	1.024	1.2241	7.41
4	5113	459.09	1818.5	23.378	1.039	1.2275	7.99
5	5429	500.44	1974.7	22.857	1.054	1.2316	8.52
6	5732	542.86	2133.8	22.336	1.069	1.2359	9.04
7	6029	586.47	2296.2	21.83	1.085	1.2404	9.55

TABLE A-16. Octane & Hydrogen Peroxide

Working Fluid: Octane (C_8H_{18}) - 25% / Hydrogen Peroxide (H_2O_2) - 75%

Electrical Energy Input kJ/g	Temperature K	Pressure MPa	Impetus J/g	Molecular Weight (-)	Covolume cm^3/g	Gamma (-)	Effective Energy kJ/g
0	3017	375.85	1486.7	16.873	1.044	1.2348	6.33
1	3432	429.84	1694.5	16.841	1.058	1.2272	7.45
2	3818	481.28	1891.6	16.781	1.07	1.2223	8.50
3	4170	530.46	2078.1	16.685	1.082	1.2193	9.47
4	4491	577.97	2255.7	16.555	1.097	1.2177	10.36
5	4784	624.42	2426.6	16.393	1.114	1.2173	11.16
6	5054	670.36	2592.9	16.207	1.132	1.2176	11.91
7	5306	716.31	2756.9	16.002	1.151	1.2186	12.61
8	5543	762.52	2919.8	15.785	1.171	1.22	13.27
9	5770	809.32	3082.9	15.562	1.191	1.2217	13.90
10	5989	856.91	3247.1	15.335	1.211	1.2237	14.51

TABLE A-17. Kerosene & Hydrogen Peroxide

Working Fluid: Kerosene ($C_{33}H_{64}$) - 20% / Hydrogen Peroxide (H_2O_2) - 80%

Electrical Energy Input	Temperature	Pressure	Impetus	Molecular Weight	Covolume	Gamma	Effective Energy
kJ/g	K	MPa	J/g	(-)	cm^3/g	(-)	kJ/g
0	3352	352.6	1446.4	19.271	0.899	1.214	6.75
1	3748	398.2	1624.8	19.182	0.92	1.2088	7.78
2	4099	441.3	1791.1	19.029	0.942	1.2061	8.69
3	4409	482.6	1947.9	18.818	0.964	1.2052	9.49
4	4684	522.9	2098.5	18.56	0.987	1.2056	10.20
5	4936	563.0	2246	18.272	1.011	1.2067	10.86
6	5170	603.4	2392.5	17.967	1.035	1.2085	11.47
7	5393	644.5	2539.7	17.654	1.059	1.2106	12.05
8	5606	686.4	2688.7	17.337	1.083	1.2131	12.61
9	5814	729.3	2839.8	17.023	1.106	1.2157	13.16
10	6018	773.4	2993.7	16.714	1.129	1.2184	13.70

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